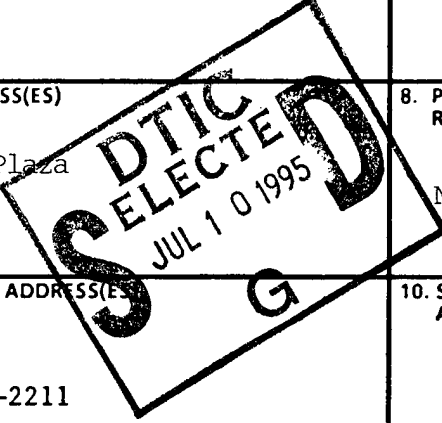


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Transmission Techniques Tactical Switched Network Services

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U.S.Army Research
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***** EXECUTIVE SUMMARY *****

The needs of the Army for a capability to utilize the "common user" switched network to interconnect data terminals and processed video intelligence data in the forward combat zones is the primary focus of this study and report. The study is to be completed in three phases, identification and characterizing the requirements (this period), technology issues in providing the services including a candidate specification (second period) covering the functions and protocol(s) which need to be embedded in the Video Packet Assembler/Disassembler (VPAD) to process video and data, and the third period would conclude in a final specification and development of an integrated video/switched digital service model.

A prior study by SCS Telecom Inc.(see bibliography), described the technology which existed at the end of 1988 and projected vigorous developments in the field of compressed video. The abbreviated schedule of this initial period did not allow sufficient time to reassess the projection, and the study period was restricted to describing the physical, operational and transmission problems most likely to be encountered in introducing data terminals into the tactical 16 Kbit voice switched network of MSE and TRITAC equipment.

Attempting to reconfirm the availability of compressed video transmission systems, a second survey of companies involved in video compression was conducted as part of the second phase of the ARO study. Unfortunately, the second survey found activity only in the "freeze frame" area of video compression and almost exclusively as PC adapters. The method of transmission for the freeze frame was via T1, T2 or higher transmission systems or computer bus inter-connections. For military applications, this would be the equivalent of single frame surveillance at about one frame per minute which is unacceptable for most platforms and most scenarios.

The digital switched common user networks utilized by the Army, Air Force and Marines are primarily based on voice transmission. While specialized data terminals handling record traffic were encompassed by the system design, the network is sized and populated to switch voice traffic. Trunk group capacity, routing and signalling are tailored to the need to communicate voice between wire and radio subscribers. A small packet switching capability was added to the MSE switches, but since the packet capability is only a single channel, the Army proponents of this Army Research Office (ARO) grant considered the investigation of switched circuit data handling to be more productive for this study.

Digitized compressed video data has similar characteristics to voice in that loss of a pixel or pixel group within a refresh cycle is not catastrophic. Acceptable video distortion (loss of a pixel group) for reasons of jamming, noise bursts or lost packets can be tolerated in most operational intelligence scenarios. Transfer of data base information is less tolerable to lost packets since corrupted data which the protocol is unable to correct can lead to more serious intelligence or operational failures. The body of this report attempts to define the problems associated with transmission problems caused by "least favorable" circuit usage, failed circuits, preemption and the ability of the video packet assembler/ disassembler (VPAD) to shut down disconnected lines with automatic adjustment of the adaptive time compression (ATC) as a function of the number of available useable interconnections. While this study quantifies the disruptions to transmission of video and data, further assessment of the quality of the transmission is needed to identify the robustness of the protocols to be recommended and the recovery actions necessary to maintain adequate quality of data transmissions for the scenario.

Finally, the physical limitations of the interconnections from the data terminals to the switched network are characterized for consideration in any model development. The MSE network was sized for voice users with limited spare circuits. As a result, limited ability to care for the needs of troop concentrations and/or users were identified. In some cases, data terminals requiring multiple circuits for timely transmission of data, may find insufficient circuits available which can be tolerated within the dynamic range of the Adaptive Time Compression (ATC) after it has been fixed. Although the calculations for the ATC buffer size indicate that a maximum of 60 Kbit of storage is required for the transmission factors considered to date, further study is required of all potential transmission problems and all modes of data in all combinations before a final ATC buffer size can be recommended.

At this phase of the study, the findings are very promising and the transmission of low speed and mid speed data under the control of a VPAD is both feasible and practical. A more intense study of all transmission concerns is recommended before entering a hardware design phase or before any attempt is made to determine any packaging (functional locations) decisions. Premature hardware design attempts are not recommended until the study is completed and the hardware interfaces and protocols are able to be firmly stated. The current multiplexer effort initiated by CECOM does not consider any of the signalling, buffering (ATC), protocol requirements, signalling sequence requirements, data device control requirements, or any of the suspected transmission problems which would require additional black boxes to compensate for the unique characteristics necessary to be considered for variable speed data transmission over voice dial-up tactical switched networks. Trade-off studies concerning the total requirements are needed before any serious hardware development is practical. If the need for a dial-up data transmission capability is considered essential at this time, these requirements should be identified and added to this study.

If the need for these capabilities becomes more urgent, the study work could be accelerated. The study could easily be compressed into one year to consider all aspects of the problem, six months for selection of the protocols and assignment of functions to design objective hardware boxes. Much of the coordination effort between the user and developer could also be accomplished in parallel with the study.

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1.0 PROBLEM STATEMENT

The Army has a need for a wide variety of communications services after moving into tactical areas from their garrison locations. The many special weapon systems currently fielded or planned to be fielded are rapidly depleting the available military frequency allocations and are fully tasking the limited supply of communications personnel required to install and maintain these systems. Forward looking engineers at CECOM would like to avoid these problems by utilizing the switching network being fielded as a common user area system. Specifically, this network is composed of the TRITAC/MSE (Mobile System Equipment) systems which are projected to be used in the Army into the Post-2010 period. It is the intent of this study to identify terminal equipment which can interact with the switching network as line interface equipment to provide the types of communication services envisioned for the Post-2000 period. Identification and description of the communications services needed by the Army was accomplished by a study report entitled "Broadband and Narrowband Switch Network Architecture" which was prepared and delivered by SCS Telecom Inc. in early 1989.

This study identifies "needs" for data transmission ranging from slow tele-metering of a few bps to high definition video in the 20 Mbps range. Broadband networks will be needed to support the distribution of these services, which will include videophone, video conference, multi-cast TV and reconnaissance/surveillance with high quality, full motion video pictures. The study also identified a need for an "adaptive time compression" (ATC) technique to buffer necessary data when throttling was required for thin capacity transmission pipes.

2.0 CONCLUSIONS AND RECOMMENDATIONS

While the functions of the VPAD are not currently established and approved requirements, the need for video surveillance in the battle field is considered an unstated requirement. Although such a requirement could evolve as a weapon system with dedicated communications, this study is considered a necessary step to determine if the system can be integrated into the common user communications network which is now depicted as the MSE/TRITAC tactical communications system. The first study established the basis for further study of the difficulties in integrating the services into the common user network. A continued study of the effects of the requirements on the intended network has yielded a promising approach to achieve the service within the confines of the voice switched network.

The apparent effects of the data transmission within real time communications on the voice network which has a primary role in satisfying communications for the tactical commanders, is not considered detrimental to that system's mission. As a condition of establishment of requirements on fielded systems, the study of the effects on the system must be undertaken. To this end, CECOM has taken the appropriate steps to ensure that the added requirements do not interfere or jeopardize the mission of the fielded system. Factors influencing the introduction of a new requirement on the present system are the primary goal of this study.

The effect of the new data transmission requirements on the current MSE/TRITAC network is discussed in this report. While further study is necessary to insure that the new requirements are possible and cost effective, it appears at this time that the voice common user network can sustain the data requirements described below. Further study of the effects of the normal activities of the switched network is justified before hardware design is implemented. These study objectives include the effects of the network requirements as well as new requirements on the data transmission.

3.0 REQUIREMENTS DESCRIPTION

3.1 VIDEO REQUIREMENTS

Video requirements can be described as ranging from limited motion field of vision including both stable platforms and slow moving subjects to high speed field of vision with fast moving platforms. While the former is very receptive to compression techniques, the latter requires very high quality to be of any use to the battlefield commander. We therefore find it necessary to differentiate between classes of video by bit rate. Low resolution video requirements such as the video phone can be compressed by transmitting the initial screen and updating only those portions (sectors, lines or pixels) of the screen in which changes are detected. Some suppliers of compressed video devices have successfully transmitted satisfactory pictures over 128 Kbit/sec transmission systems. Any rapid motion at these compression rates is usually accompanied by "tearing" of the image at the point of motion. At least one algorithm being supplied as part of the compression device, predicted the motion based on previous frames and was able to transmit a very good quality limited motion picture with a 64 Kbit/sec transmitter.

Medium motion video conferencing or tele-broadcasting is currently being accomplished using pre-established T-1 circuits (1.544 Mbps) in commercial networks. The most common utilization of these services are in commanders conferences and training sessions in garrisons which are serviced by commercial telephone networks.

The third class of video service is in the conventional and high quality (high resolution) video. Some R&D is currently underway to compress high quality video into the standard bandwidth of conventional TV but few of the suppliers have been willing to release any information. The bandwidth for this type of service is in the order of 100 Mbps. With the ever growing need for communications services, the RF band will continue to have user pressures which will require new compression techniques.

3.2 DATA REQUIREMENTS

The need for compressed data exchange between elements of the Army in textual or computational form is driven by an explosion of personal computer (PC) or work station terminal usage. As the needs expand, the requirements for larger and larger data bases have also increased. The PC capacity has limits which in turn require the architecture to turn to centralized large capacity storage media with distributed work stations. This in turn has required a growth in data base transfer between centralized computer facilities with large storage media and the user of the data stored in central facilities. In order to use the data, down loading of programs and files to the work station or PC terminal is necessary. Rapid transfer of files and data base must be accomplished without error. Corrupted files of data either render the terminal useless or make erroneous computations. Data

transfers must therefore utilize a vibrant protocol with a forward error correction (FEC) scheme selected for the error environment.

Data transmission requirements in the range of 10 bps to 10 Kbps have existed for many years and protocols and FEC codes have been developed and are in use. Thus, in this study, we have focused on the new needs of the Army, which is to packetize mid range data for serial transmission through multiple tactical circuits of the MSE switching network.

3.3 DESCRIPTION OF REQUIREMENTS WITHIN MSE/TRITAC

The TRITAC system equipment evolved from Ad Hoc requirements from the Services and Agencies. During the allocation of the military needs into equipment specifications, studies were performed which were designed to encompass the majority of the stated requirements. TRITAC equipment was to bear the brunt of the evolution to a digital communications system. The most prominent requirement was that of voice communications which led to the selection of continuously variable slope delta modulation (CVSD). The bit rate was a compromise between bandwidth and the need for successive analog to digital conversions. Thirty-two Kbps was chosen as the loop (line/channel) transmission rate for the TRITAC initial fielding with an automatic capability to drop down (rate convert) to 16 Kbps when the network became primarily digital. MSE was fielded without any rate conversion capability and is capable only of 16 Kbps operation.

3.3.1 TRITAC INTERFACE

At Echelons above Corps (EOC), the TRITAC switching system equipments are in the process of being modified for compatibility with the MSE. After modification, including interface with the RAU, MSE units will be able to transit through EOC without any loss of capability.

3.4 VPAD REQUIREMENTS

The projected requirements for the VPAD are to accept one or more input devices having low speed to medium speed transmission requirements. Devices in this bit rate range include TTY, telemetering equipment, Personal Computers, Video Phone, and compressed video. The functions which must be performed in order to introduce data into the real time switched circuits of the MSE/TRITAC network include the following:

- Packet assembler/disassembler. It is the ability of VPAD to construct packets from the input stream and attach the necessary overhead bits (for identification, error detection, etc.) and the ability to disassemble the packets and form the original bit stream.
- Packet storage (ATC), It is the ability of VPAD to store information bits and transmit them over a 16 Kbps channel.
- Data signal manipulation/processing, and protocol control, the VPAD should perform the signal manipulation and processing functions of the information protocol (attaching protocol overhead and performing functions such as error control, synchronization, frequency, etc.)
- Mux/Demux, Since the VPAD may connect a number of devices, it must be capable to multiplex and demultiplex the traffic.
- Transmission control; The VPAD must control the transmit information bit using the right channel encoding scheme used on tactical network and meet the physical interface requirements.
- FEC coding/decoding; In some types of traffic, such as real time video, the use of error recovery schemes such as automatic-repeat request (ARQ) may not be appropriate. Having the capability of forward error correction enhances the application of VPAD.
- Line monitoring: The device should be capable to monitor the line performance (such as error rate, synchronization, etc.)
- Call set-up/termination
- Encryption/Decryption (if required)
- Switch connection

While the above functions can be implemented into various forms of equipment (separate boxes), each must exist in some manual or automated form. As an example, call setup could entail switching a telephone to the lines into the switched network, and manually dialing the desired connection or the signalling could be automatically done on each line by the transmission controller. The decisions as to where to locate the equipment which will perform the function will have to be made when the hardware design phase of the project is reached. For the present, all the functions are considered to be part of the VPAD.

The output side of the VPAD would be two or more 16 Kbps channels/line into one of the MSE or TRITAC switches. One of the output channels could be a control channel which would carry the connection and transmission/fault/default data to enable the originating and terminating VPADs to negotiate the number of channels, the bit rates being used, retransmission of bytes or packets, loss of channels, etc. The VPAD user would set up the VPAD data to describe the data device(s) being connected, the number of channels/line available for use and the precedence and other identification data necessary for the VPAD. The VPAD projected in this study would require the functionality to automatically place calls between the originating and terminating VPAD with connection information and metering information passed via the control channel or via control data included in the packet protocol. The details of the VPAD control channel (if required) are not contained in this report and would be a thrust of the follow-on phase of this three phase study.

3.5 PHYSICAL REQUIREMENTS

The TRITAC/MSE switch channel/line characteristics are such that a two bit buffer is included in the switch design. The buffer is required to compensate for long/short wire lines. The distance from the VPAD to the switch connector allows from zero to 4 kilometers of WF-16 wire or the equivalent loss by a loop group transmission device. The VPAD requirements are to be physically able to be connected via WF-16 field wire to slotted wire connectors which are grouped in 13 quad group connectors to connect to the MSE/TRITAC switchboards. The input side of the VPAD to the data devices have not been identified as part of this study. A device controller would be required to start the data transmission once the connection(s) are completed between VPADs.

3.6 TRANSMISSION REQUIREMENTS

While the input data rates to the MSE/TRITAC switches have been fixed at 16 Kbps per channel, the protocol for the VPAD could range from stolen least significant bits from each transmission byte or included in the packet control information or, could be contained solely in the overhead control channel. These decisions require careful consideration as part of the selection process of the protocols to be used by the VPAD. Whereas the channels/line setup is a function of the maximum bit rate to be transmitted, the control mechanism for each channel has a number of options as stated above. Many of these decisions involving the protocol selection and control mechanisms will require considerable interplay with the users. The selection of the classes of service (precedence levels, identification codes, destinations, satellite use, etc.) are controlled by the Army outside of the developing community. As such, considerable time will be expended in reaching agreement between representatives of the user and developer communities on new communication requirements. There may also be a requirement to make changes to the MSE/TRITAC switches to accept the VPAD data connections.

4.0 VIDEO PROCESSING

4.1 VIDEO RECORDING

Although video camera recorders (camcorder) are being improved each day at an impressive rate, the need for digital output from the recorder has not as yet surfaced as an integral part of the device. This is not to infer that such a requirement may not soon surface, but we are not as yet aware of the need to develop, or of the availability of a digital output recorder. In any event, such a need would be commercially motivated and would be based on new commercial standards. The study would then need to focus on the adaptability to military uses and the acceptability of the end product.

4.2 VIDEO PROCESSING (DISASSEMBLER)

As stated above, the need for preprocessing of the camcorder output is to insure that the output is compatible with the user transmission from the platform to the ground. If analog, the output will be required to be compatible with the radio assemblage or other transmission equipment in use to transmit to the video digital processing circuits. The initial transmission of the video picture must be transmitted as a complete screen for the first few frames before any compression can take place. The processing algorithm used to compress the video signal has as yet not been determined or selected. After the compression techniques have restructured the video signal, the compressed signal is digitized into packets with the proper headers and envelopes set in place. The packets are then registered with the control circuit for accountability and are transmitted into the MSE channel(s) selected for the packet.

4.3 ADAPTIVE TIME COMPRESSION (ATC)

The Adaptive Time Compression feature of the VPAD has the following functions: The initial full screen will in most cases have a greater number of packets than the capacity of the digital switch channel(s)/line are capable of accepting. The ATC will then buffer the video packets for sequential transmission until the video data is put into the compressed data mode and the data being transmitted is equal to or less than the capacity of the switched channel(s)/line. The ATC must be dynamic in that in some cases, the need to update the video picture (when motion is detected in the video signals being processed and compressed) may be greater or less than the capacity of the channel(s)/line. The effect of the ATC is to buffer the video signals until packets being transmitted are equal to or greater than the video signals inputted into the VPAD from the data device. This buffering of signals by the ATC will be required during the transmission of the data. The amount of buffering required by the ATC is a function of the amount of screen motion or during decreased line/channel capacity resulting from preemption or switch/transmission equipment failures. These events and the calculations of the required buffer size is provided below. Trade-offs in the ATC buffer size are also discussed below.

The ATC function in the receiver VPAD are the inverse of the transmitter VPAD. The over-all function of the ATC is to allow the sequential transfer of video data in a manner that approaches real time

4.4 REBUILDING THE DATA (ASSEMBLER)

transmission of the video pictures. While the discussion above has concentrated on video as the most stringent transmission requirement, these requirements would also need to be imposed on transmission of any of the data devices identified as candidates for connection to a VPAD. Data transmission of computer files is one example of where the ATC function would be required to insure that files are transferred in an error free form. Some other considerations which need to be studied concern high noise environments which require repeated transmission (ARQ) of packets or bytes not correctable by Forward Error Correction (FEC) codes.

As the packets of transmitted data are received at the VPAD, the data is reconstructed in the form it was in before being packetized and all headers and envelopes are removed. The inverse process is repeated and the data is transferred to the data device. The VPAD ATC functions to buffer the information until the data device is ready to receive the data in the form it is designed to accept. If video, the entire screen is rebuilt and transmitted to the video receiver at the rate normally accepted. If the data is compressed, the VPAD function is to reconstruct the frame and transmit it to the video receiver. Again, if the data is a file transfer, the VPAD functions to insure that the FEC or control channel has correctly functioned and that only error free data is introduced into the data device. The protocol of the control channel and the bytes/packet as well as the data transfer protocol between the VPAD and the data device insures that the data is not contaminated by the transmission media.

5.0 NETWORK CONSIDERATIONS

An assessment of the potential concerns associated with transmission of packetized data through a real time switched network has been made to determine what specific considerations need to be addressed as part of this study. While there may be other potential concerns, the following are identified as known factors which would influence the design of the VPAD:

- Data transmission delays
- Trunk resync cycles
- Crypto resync cycles
- Channel preemption
- Burst error environments

5.1 WORST-CALL CONNECTION OF MULTIPLE CHANNELS

Call set-up in the fielded MSE/TRITAC switching system is dependent upon a number of factors. While the system attempts to find the best possible path for each call, availability of unused channels between switches, precedence levels, transmission, trunk or switch outages, etc., all play a part in the call route selection process. The tactical network is deliberately packaged into mobile shelter assemblages to provide maximum survivability as a battle progresses. Switches are required to move, subscribers are required to move, and at any time real connectivity between sections of the Corps may not exist. The network control is such that sufficient nodes should be connected to enable priority traffic to find connections. But even in a stable network, calls placed from a single location to a single destination may be forced into different routes depending on the network conditions at the time of the call requests. The probability exists that two calls from the same node to a common node may end with one call using a single trunk and a second call traversing many nodes before it can be completed. For this reason, this study has attempted to account for variations in transmission delays to data between VPADs.

5.2 TRUNK RESYNC CYCLES

MSE/TRITAC switches are rigidly timed using atomic timing standards. However, switches do need to periodically resync their trunk buffers when there are differences in the rates at which they are clocking their trunk groups. Buffer resettings are done instantly, but will affect data transmission. While voice connections are tolerant of these resync cycles, data can be corrupted.

5.3 CRYPTO RESYNC CYCLES

The trunk groups of the MSE/TRITAC network are secured by trunk encryption devices (TEDs) which can also lose sync during transmission interruptions. This causes the crypto equipment to enter into a resync cycle which can corrupt data traversing the trunk group. Again, similar to the trunk resync cycle, data transmissions must consider this characteristic of a voice switched network.

**5.4
CHANNEL
PREEMPTION**

One of the most prevalent factors which would affect the data being transmitted over multiple channels of the switched network, is preemption. The VPAD connection(s) through the network may experience preemption of one or more of its connections. Reconnection of these paths would require seconds of time. During the period of time that the path is lost, the ATC function of the VPAD must adjust for the loss of transmission capacity. If the data being transmitted is compressed video, a control decision must be made to terminate the transmission, continue with reduced capacity or adjust the transmission while a new path is being reestablished. While exact preemption numbers are not available for the MSE/TRITAC network, this characteristic of the voice network must be considered and decision prompts must be included in the design of the VPAD control circuits.

**5.5
NOISE
ENVIRONMENTS**

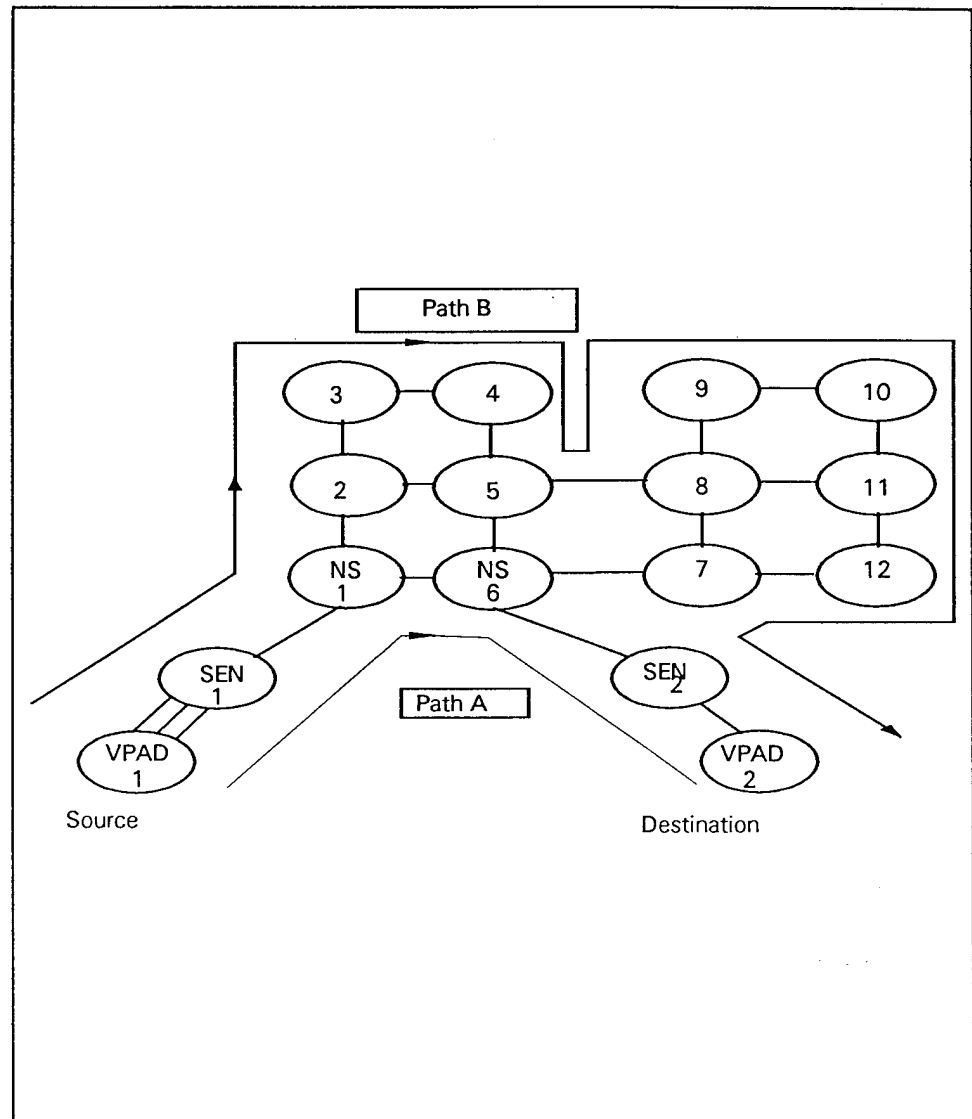
The battleground of Post 2000 will be electronically noisy. Both random and burst errors will decidedly affect the transmission of data in the network. While the causes of the noise environment are able to be projected, the effects have not been quantified.

An effort must be made to acquire the effects of noise on data transmission and the appropriate decisions included in the control parameters.

6.0 VPAD CALCULATIONS

This section indicates the effects of some of the problems on the VPAD buffer. A typical configuration is shown in Figure 1.

Figure 1 - Typical Network Configuration

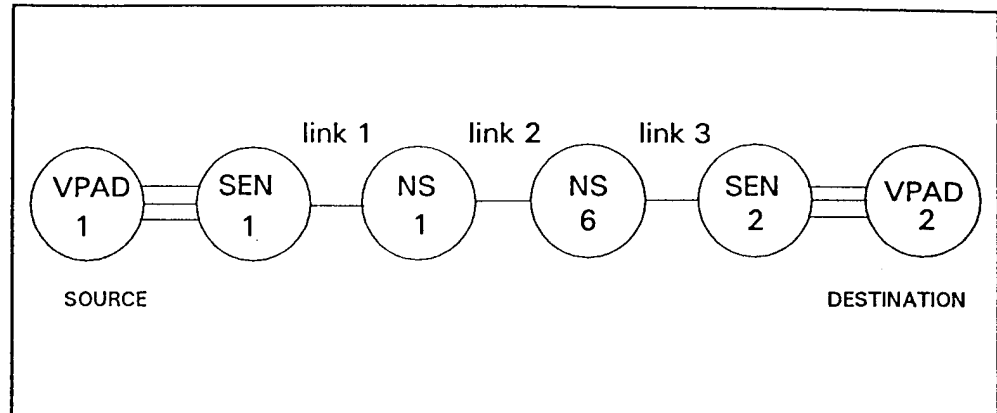


6.1 BEST PATH / WORST PATH DIFFERENCES

The determination of maximum and minimum time for VPAD-TO-VPAD connections is presented below:

The path between a source VPAD1 and a destination VPAD2 consists of a number of links. For example, as shown in **Figure 2**, path A consists of the link VPAD1 to SEN1, link SEN1 to NS1, Link NS1 to NS6, Link NS6 to SEN2, and SEN2 to VPAD2.

Figure 2 - Path A



Since the distance between VPAD1 and SEN1 is small, we can neglect the propagation time from VPAD1 to SEN1. Similarly, we can neglect the propagation time from SEN2 to VPAD2.

Thus, the total time needed to transmit a packet from VPAD1 to VPAD2, T , consists of the following components:

T_{VPAD1} = the packet processing time and queuing time at VPAD1 and the transmission time at channel speed of 16 Kbps.

$T_{(SEN1 \text{ to } NS1)}$ = Propagation time from SEN1 to NS1

$T_{(NS1 \text{ to } NS6)}$ = Propagation time from NS1 to NS6

$T_{(NS6 \text{ to } SEN2)}$ = Propagation time from NS6 to SEN2

T_{VPAD2} = Packet processing time (this includes assembling, resequencing and additional data protocol processing)

Thus,

$$T = T_{VPAD1} + T_{(SEN1 \text{ to } NS1)} + T_{(NS1 \text{ to } NS6)} + T_{(NS6 \text{ to } SEN2)} + T_{VPAD2} \quad (6.1.1)$$

Now, if we assume that the distance from SEN to LEN and from LEN to LEN are approximately equal.

Then,

$$T_{(SEN1 \text{ to } NS1)} = T_{(NS1 \text{ to } NS6)} = T_{(NS6 \text{ to } SEN2)} = T_p$$

Where T_p = the propagation time over one link. Hence,

$$T = T_{VPAD1} + 3T_p + T_{VPAD2} \quad (6.1.2)$$

PATH A represents the best path for VPAD1 to VPAD2 communications, it includes only 2 NS' and results in the best (minimum) total time needed to transmit a packet from VPAD1 to VPAD2, T_{BEST}

$$T_{BEST} = T_{VPAD1} + 3T_p + T_{VPAD2} \quad (6.1.3)$$

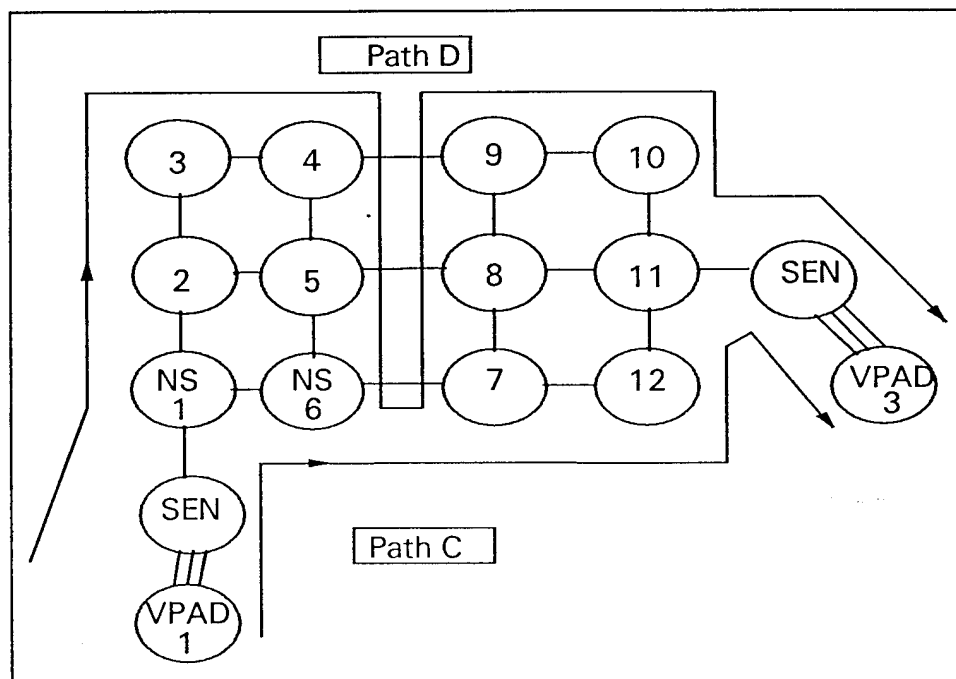
The difference between T_{BEST} and T_{worst} , defined as $T_{\text{Difference}}$, is given by

Note that $T_{\text{Difference}}$ here represents the worst case difference. See equation (6.1.5). For example, **Figure 3** shows the best path (path C) and the worst path (path D), for VPAD1 to VPAD3 communications. In this case, we have:

$$T_{\text{Worst}} = T_{\text{VPAD1}} + 12 T_p + T_{\text{VPAD3}} \quad \text{and}$$

$$T_{\text{Difference}} = 6T_P, \text{ as given in equation (6.1.5)}$$

Figure 3 -VPAD1 to VPAD3 Communications



By inspection, we conclude that path A and Path B provide us with the worst case. Thus, $T_{\text{Difference}}$ is $10 T_p$.

T_p is the link length divided by the speed of light (3×10^5 km/sec). For terrestrial links, T_p is generally small.

For a terrestrial link of distance 30 kilometer, T_p equals 0.1 m.sec.

For a satellite link, T_p equals 250 m. sec.

Assuming only one satellite link in the worst path, we get

$$T_{\text{Difference}} = 9 \times 0.1 + 1 \times 250 = 250.9 \text{ m. sec. (6.1.6)}$$

6.2 BUFFER SIZE CALCULATION

6.2.1 THE SOURCE VPAD (TRANSMITTING VPAD)

In this section, we determine the buffer requirement for the VPAD. We will distinguish between the transmitting VPAD and the receiving VPAD regarding the buffer required.

The transmitting VPAD establishes N parallel channels. If one channel is reserved for control, N can be 12 channels or less depending on the network load. To determine the buffer size required at the transmitting VPAD we analyze the VPAD using queuing theory. VPAD can be viewed as a single-server queue for every outgoing channel. Assuming that bits are grouped into packets (say, each packet is 1000 bits), and assuming that user traffic arrives to the VPAD following a Poisson process, then using the well-known $M/D/1$ queuing result, we obtain the following formula:

Average packets waiting in the buffer q is given by

$$q = p^2 / 2(1 - p) + p \quad (6.2.1)$$

where P represents the channel utilization which is equal to the user rate divided by the channel rate.

It should be noted that the Poisson process describes the traffic arrival process. It has been widely used for both data and voice traffic. Regarding the video traffic, extensive research has been conducted to study the video traffic characteristics. A number of stochastic processes have been suggested to model video traffic, for example, see references [2] through [4]. The poisson process remains as a good approximation.

The formula above will be applied to the three cases of low-speed data, mid-speed data and high-speed data, to obtain the buffer size.

6.2.1.1 LOW-SPEED DATA (2.4 Kbps)

In this case the low-speed data requires one channel of 16 Kbps. Thus, the channel utilization, p , is given by $p = 0.115$. Using equation (6.2.1), we obtain

$$q = 0.163 \text{ packet}$$

Thus a one packet buffer is sufficient.

6.2.1.2 MID-SPEED DATA (50 Kbps)

In this case, the mid-speed data requires 4, 16Kbps-channels, with each channel carrying $50\text{Kbps} / 4 = 12.5\text{Kbps}$. Thus, each channel utilization $p = 12.5/16 = 0.78$

Using equation (6.2.1), we have,

$$q = 3.28 \text{ packets}$$

Working with a 50% safety factor (to reduce the probability of buffer overflow) results in a seven packet buffer size per channel being sufficient, leading to a total of a 28 packet buffer size per VPAD.

**6.2.1.3
HIGH SPEED
DATA (10 Mbps)**

In this case, we will use the maximum number of channels available, i.e., 12 channels. Each 16 Kbps channel carries a load of $10 \text{ Mbps}/12 = 833.3 \text{ Kbps}$. Obviously, this exceeds the channel rate resulting in a large number of queued packets. Accordingly, the buffer size should be at least equal to the volume of data transmitted during a given call.

If we make the assumption that five image files, on the average, are to be transmitted during a call. Each image includes 512×512 pixels and each pixel is represented by an 8 bit code. One image then requires approximately 2 Mbits of data. For compressed video at say 20 images per second, 40 Mbits/sec. is required to be transmitted which is equivalent to 40 K packets/per second. The buffer size is then forecasted to be a minimum of 40K packet buffer if the transmissions speed is equal or greater than the 40 Mbits/sec. A more intense look at dynamic compression techniques is intended in phase two of the study to determine the most realistic size of the buffers for continuous video transmission as well as the maximum size buffering necessary and the transmission delay in achieving the video transmission.

**6.2.2
RECEIVING VPAD**

The buffer at the receiving VPAD should be large enough to hold the packets that are arriving out of sequence. As shown in equation (6.1.6), the time difference, $T_{\text{Difference}}$, between T_{worst} and T_{best} is equal to 251.8 msec., (assuming only one satellite link in the worst path). Thus the buffer at the receiving VPAD should be capable to hold the packets for at least a duration of 251.8 msec. For 16 Kbps, a 251.8 msec. is equivalent to 4024 bits, (i.e, 5 packets per channel). Below, we provide the buffer size for the receiving VPAD for the three cases of low speed data, mid speed data, and high speed data.

**6.2.2.1
LOW-SPEED
DATA (2.4 Kbps)**

Low speed data requires only one 16 Kbps channel. Thus, packets arrive in order. A one packet buffer is sufficient.

**6.2.2.2
MID-SPEED DATA
(50 Kbps)**

In this case, four 16 Kbps channels are required, since each channel requires a buffer of 5 packets for sequencing. A total buffer size of 20 packets is needed.

**6.2.2.3
HIGH-SPEED
DATA (10 Mbps)**

In this case, twelve 16 Kbps channels are required. Hence, the total buffer size required is 60 Packets. The results are shown in Table 1.

Tabel 1 Buffer Size for the VPAD (in packets)

Data Rate	Number of 16Kbps Channels	Channel use P	Transmitting VPAD		Receiving VPAD	
			Buffer size Channel	Buffer size VPAD	Buffer size Channel	Buffer size VPAD
Low Speed (2,4Kbps)	1	15%	1	1	1	1
Mid Speed (50Kbps)	4	78%	7	28	5	20

6.3 DISRUPTED CHANNELS/LINE EFFECT ON BUFFER

Loss of one or more of the VPAD channels can occur due to switch failure or as a result of pre-emption. Below, we study the impact of such event on the buffer size of both the transmitting and receiving VPAD.

6.3.1 TRANSMITTING VPAD

6.3.1.1 LOW-SPEED DATA (2.4 Kbps)

Low speed data requires only one channel. Define $T_{re-establish}$ as the time required to re-establish a replacement channel. The buffer should be capable to store all the data arriving during $T_{re-establish}$.

Assuming $T_{re-establish}$ equals to 10 seconds. Then,

$$\begin{aligned}
 \text{Buffer size in bits} &= 2400 \text{ bps} \times T_{re-establish} \\
 &= 2400 \times 10 = 24,000 \text{ bits} \\
 &= 24 \text{ packets}
 \end{aligned}$$

6.3.1.2 MEDIUM-SPEED DATA (50 Kbps)

In this case, four 16 Kbps channels are required. Losing one or more channels will result in redirecting the traffic to the remaining channels leading to a large number of queued packets. Thus, the buffer size should be capable of storing the largest file size expected to be transmitted during a call. As before, for a file size of 5 Mbytes (i.e., 40K packets), the transmitting VPAD buffer size should be 40K packets.

6.3.1.3 HIGH-SPEED DATA (10 Mbps)

This case is similar to the medium speed data. The transmitting VPAD buffer size should be 40K packets.

6.3.2
RECEIVING PAD

Loss of one or more channels has no impact on the receiving VPAD buffer. These results are summarized in Table 2.

Table 2 - Impact of Path Loss on the Transmitting VPAD

Data Rate	Buffer Size per Channel	Total Buffer
Low Speed (2.4Kbps)	24	24
Medium Speed (50Kbps)	3.33K	40K
High Speed (10Mbps)	3.33K	40K

In summary, the transmitting side of the VPAD requires more buffer than the receiving VPAD. For low speed data VPAD buffer size is 1 packet for both the transmitting and receiving VPAD. For mid speed data, it is 29 packets, for the transmitting VPAD and 20 packets for the receiving VPAD. For high speed the transmitting VPAD requires 40K packets, while 60 packets are needed for the receiving VPAD.

The loss of one or more channels has no impact on the receiving VPAD. The sending VPAD requires 8, 40K , and 40K packets for low, mid, and high speed data respectively.

7.0 VPAD PROTOCOL ARCHITECTURE

This section discusses the main features of the VPAD protocol architecture and functions. The VPAD protocol is basically a set of very specific rules governing the interchange of the video information bits over the Tactical Network. The VPAD control rules typically define connection set-up, control of normal video signal transfer, termination of the connection, and perhaps most important from the point of view of the user, techniques of control recovery from abnormal conditions such as; loss of a synchronization, or faults resulting from anomalies in the communication link from loss of one of the channels due to pre-emption for example.

Digitized video signals, transmitted over circuit switched networks, have traditionally been sent as a continuous stream of bits. To establish a video call, the VPAD will request up to twelve, 16 Kbps, channels to carry the video signal. To overcome abnormal situations, such as loss of one or more channels due to pre-emption, for example, the VPAD should have the capability to form packets (or messages) of bits to control recovery from these abnormal conditions.

The packets formed by the VPAD are of two types, video packets and control packets. The video packets carry the video information bits plus a number of overhead bytes. The control packets serve to generate the proper operation of the connection and to control recovery from abnormal conditions. Control packets do not carry video information bits.

It should be clear that the time it takes to establish the channel is a function of the transmission time, the propagation time and other factors, such as the switch processing time needed to establish the route. Hence, to have an accurate measurement of the time delay, we suggest sending, immediately after channel establishment, a time-stamped message to the destination VPAD. The destination VPAD responds with a time-stamped acknowledgement message. This allows the sending VPAD to know the exact path delay.

7.1 SIGNALLING MESSAGE (SM) Format

To establish a VPAD communication, the user only needs to know the number of the Called VPAD (VPAD2). Once the user dials that number, the Calling VPAD (VPAD1) sends 12 dialing tones (addresses) to allocate 12 channels, if available, in the MSE.

Once the channels have been established, CHANNEL SET packets will be sent by VPAD1 to VPAD2. The CHANNEL SET (CS) packet format will have information regarding the Called and Calling Addresses, Channel Number, Cyclic Redundancy Code (CRC) for error detection or other type of code for error correction, plus other network information. See Figure. 4.a.

7.2 VPAD Protocol Functions

The protocol functions included in the VPAD should be: Time Recording, Sorting and Mapping.

7.2.1 Time Recording

The VPAD should record the time of each channel establishment. This Time Record will be used by VPAD1 to determine, by sorting, which channel number has the shortest path in the network and know the timing difference between each path.

7.2.2 SORTING

Sorting on the established channels will be done. This Sorting will number the channels from the shortest path to the longest path. This will enable the VPAD to send the first video packet on the shortest path, the second video packet on the second shortest path, and so on. The assigned channel number will be included in the CHANNEL SET packet.

7.2.3 MAPPING

A table will be prepared to map the physical channel port with the given channel number, see Table 3.

Table 3. MAPPING LIST

Channel # Assigned	Physical Output Port
1 (Shortest Path)	8
2 (2nd Shortest Path)	3
.	.
.	.

7.3 PROTOCOL PROCEDURES

When a VPAD wants to transmit video data it generates dialing tones to establish up to 12 circuit channels. Up to 12 dialing tones are sent from VPAD1 to the originating switch (NCS) to do a flood search of VPAD2 addresses. Once VPAD2 has been found according to MSE routing procedures, for example, see reference [5], and the physical channels (up to 12) have been established, the handshaking between VPAD1 and VPAD2 takes place. VPAD1 starts by sending CS packets over every established physical channel and VPAD2 confirms by sending CHANNEL SET CONFIRM (CSC) over every physical channel. If VPAD2 is not ready to accept the video signal, say due to mal-function, it sends back a NEGATIVE ACKNOWLEDGEMENT (NA) packet. The format for the CS, CSC, and NA are shown in Figures 4.a through 4.d.

The following protocol procedures should be included: Circuit Setup Phase, Information Transfer Phase and the Circuit Tear Down Phase.

7.3.1 CIRCUIT SETUP PHASE

Here the transmission link will be established. The Calling VPAD (VPAD1) will send dialing tones to establish up to 12 transmission channels on the MSE depending on the channels availability at the time.

NETWORK CONTROL MESSAGES (PACKETS)

Call Set Messages

Channel Set	Flag	Called Address (VPAD2)	Calling Address (VPAD1)	Channel Number	CRC	Channel Set	Flag
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Fig. 4.a

Channel Set Confirm	Flag	Called Address (VPAD2)	Calling Address (VPAD1)	Channel Number	CRC	Channel Set Confirm	Flag
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Fig. 4.b

Negative Acknowledge	Flag	Called Address (VPAD2)	Calling Address (VPAD1)	Channel Number	CRC	Negative Acknowledge	Flag
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Fig. 4.c

Circuit Tear Down Message

Circuit Tear Down	Flag	Called Address (VPAD2)	Calling Address (VPAD1)	Channel Number	CRC	Circuit Tear Down	Flag
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Fig. 4.d

7.3.2 INFORMATION TRANSFER PHASE

In the Information Transfer Phase the video bits will be sent in packet form, as shown in the VIDEO packet format in **Figure 5.a**. According to the video packets generated they will be sent on the shortest path channel. For example, the first video packet is sent on the longest path, the second video packet on the second longest path, and so on. This will minimize the interarrival time between packets at the receiving end, as long as the time difference between the paths does not result in packets arriving out of sequence. If this is the case, another approach is to send the first video packet on the shortest path, second video packet on the second shortest path, and so on.

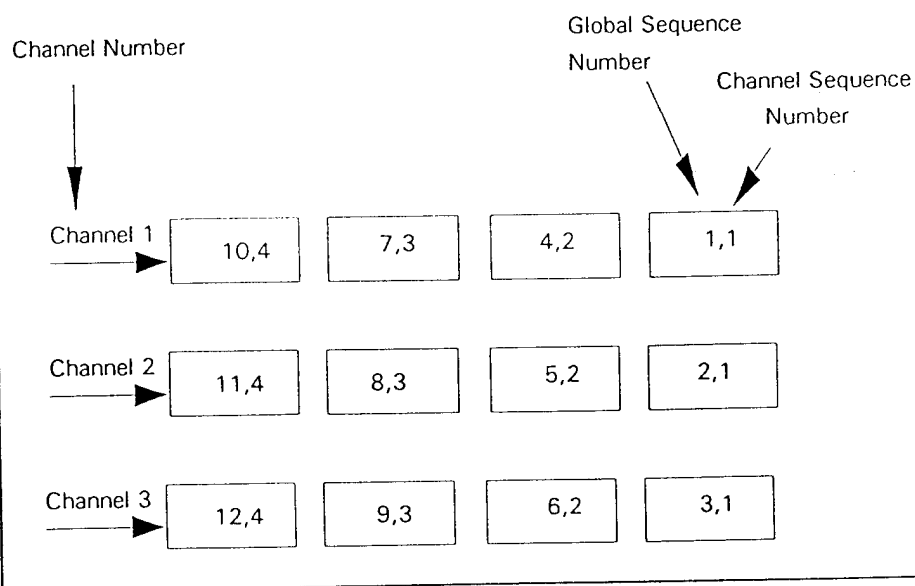
Fig. 5.a

VIDEO PACKET

Flag	Called Number (VPAD2)	Channel Number	Global Sequence Number	Channel Sequence Number	Video Bits	CRC (or FEC)	Video Packet	Flag
------	-----------------------------	-------------------	------------------------------	-------------------------------	---------------	-----------------	-----------------	------

Fig 5.b Use of Global Sequence Number and Channel

Sequence Number in the VIDEO packet format



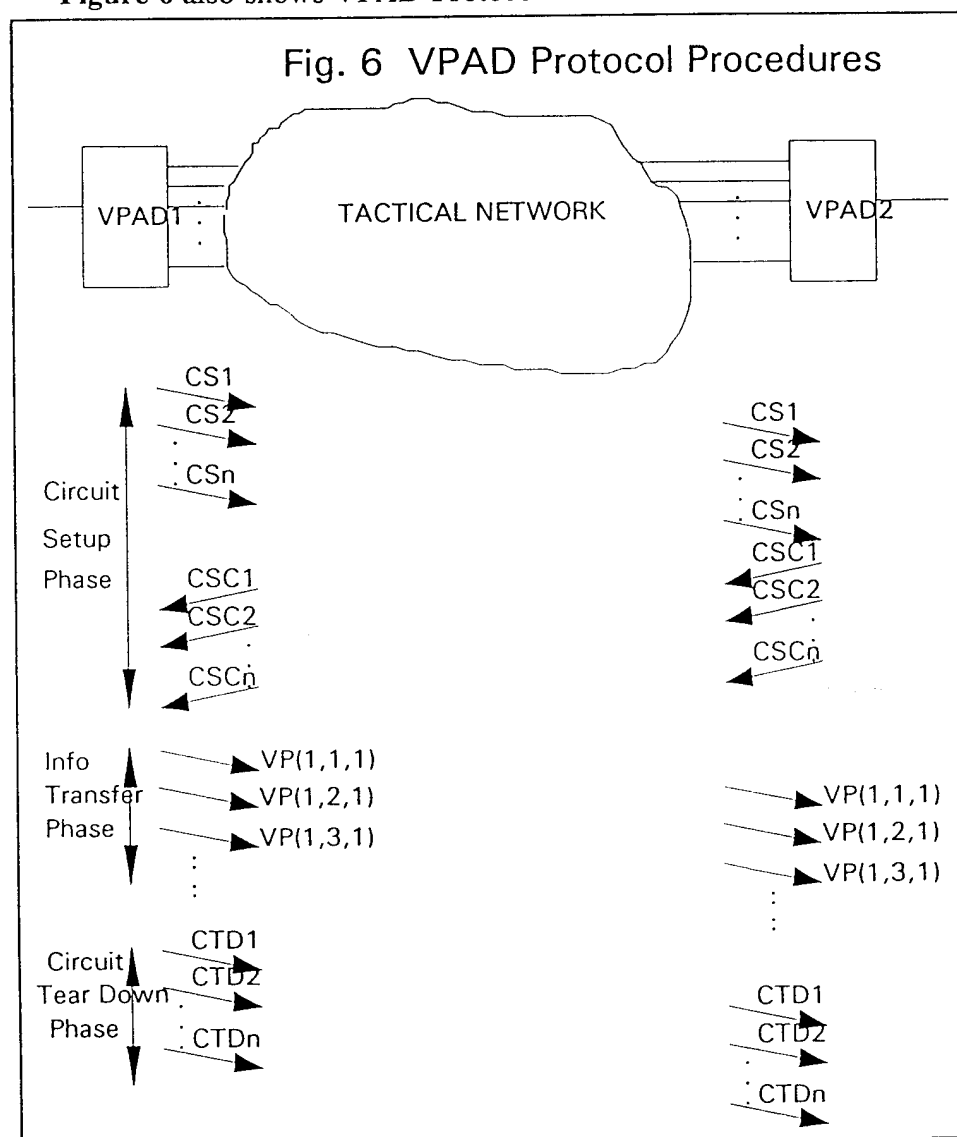
7.3.3 CIRCUIT TEAR DOWN PHASE

A Global Packet Sequence number and a Channel Packet Sequence number are needed. The purpose of the packet global sequence number is to identify the position of that packet in the whole video information bit stream. While the purpose of the packet channel sequence number is to identify the packet's position within the specific channel where its transmission occurs. Figure 5.b shows an example of 12 VIDEO packets that are transmitted in parallel over three channels, with both the global and channel sequence numbers shown.

At the end of the video transmission all the channels in the circuit are released. This is accomplished by sending the CIRCUIT TEAR DOWN (CTD) packet over every video channel. The format for CTD is shown in Figure 4.d.

Figure 3 shows a typical sequence of the three phases.

Figure 6 also shows VPAD Protocol Procedures.

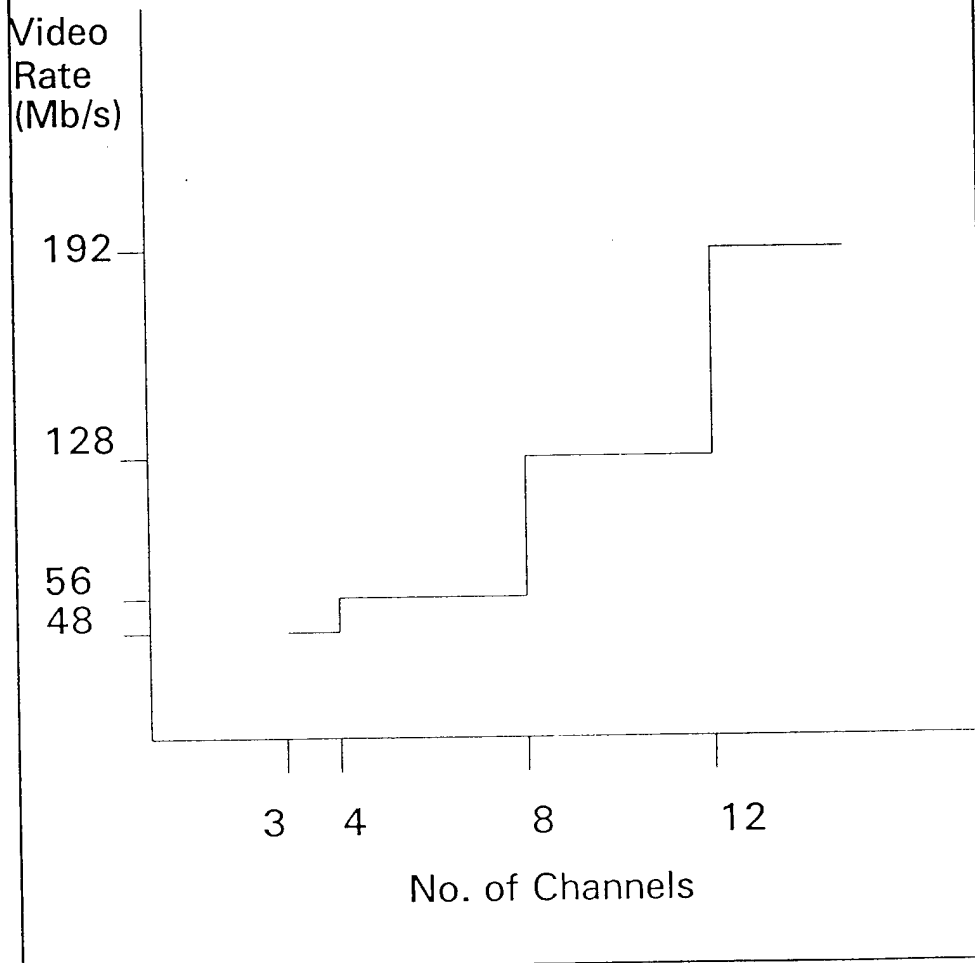


7.4 VIDEO CODING RATES

Depending on the number of channels allocated, the Video Coding Rate (VCR) will vary from 192 Kb/s to 48 Kb/s (these are recommended rates based on the available commercial video codecs) (See Figure. 7).

Video Coding Rate	Number of Channels
VCR1 48 Kb/s	3
VCR2 56 Kb/s	4
VCR3 128 Kb/s	8
VCR4 192 Kb/s	12

Fig. 7 Number of channels and their corresponding video codec rate in Mb/s



As an example, VPAD1 requests 12 channels, the network allocates only six channels, then the video codec should produce the video information bits at a rate of 56 Kbps. With a bit rate of 56 kbps, four channels are sufficient. Thus, the VPAD should release the two extra channels.

7.5 CASE OF LOSS OF ONE OF THE CHANNELS

In the event of channel loss a new Mapping Table is created at VPAD1 for the channels available. A readjustment Message (Figure. 8) is sent to VPAD2 containing the new Mapping Table. Figure 9 shows the Sorting function and the new Mapping as a result of a channel 3 loss.

CHANNEL MAPPING MESSAGES

Figure 8.a Sorting Message

Flag	Called Address (VPAD1)		Called Address (VPAD2)		New Number of Channels		Ch1 Old	Ch1 New	...		
...	Ch2 Old	Ch2 New	Ch3 Old	Ch3 New	Ch4 Old	Ch4 New	Ch5 Old	Ch5 New	Ch6 Old	Ch6 New	...
...	Ch7 Old	Ch7 New	Ch8 Old	Ch8 New	Ch9 Old	Ch9 New	Ch10 Old	Ch10 New	Ch11 Old	Ch11 New	...
...	Ch12 Old	Ch12 New	CRC		Sorting Message		Flag				

Figure 8.b Readjustment Message

Flag	Called Address (VPAD1)		Called Address (VPAD2)		New Number of Channels		Ch1 Old	Ch1 New	...		
...	Ch2 Old	Ch2 New	Ch3 Old	Ch3 New	Ch4 Old	Ch4 New	Ch5 Old	Ch5 New	Ch6 Old	Ch6 New	...
...	Ch7 Old	Ch7 New	Ch8 Old	Ch8 New	Ch9 Old	Ch9 New	Ch10 Old	Ch10 New	Ch11 Old	Ch11 New	...
...	Ch12 Old	Ch12 New	CRC		Readjustment Message		Flag				

When one of the channels is lost during transmission, two problems arise:

(a) The number of available channels is reduced.

Depending on the number of channels that are left active, the transmission goes to a lower bit rate (VCR). If the number of channels are

eight with a Video Coding Rate of 128 Kb/s (VCR3) and a channel is lost, leaving seven channels available, the Video Coding Rate then goes to 56 Kb/s (VCR2). The transmitting VPAD should release the unneeded channels (three in this case).

Fig. 9.a Sorting according to Call Accepted Arrivals

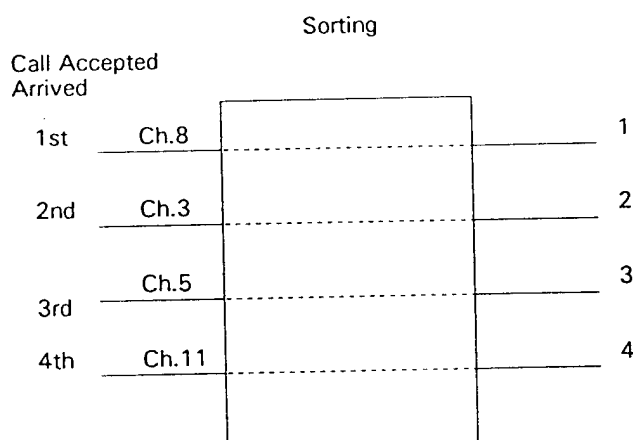
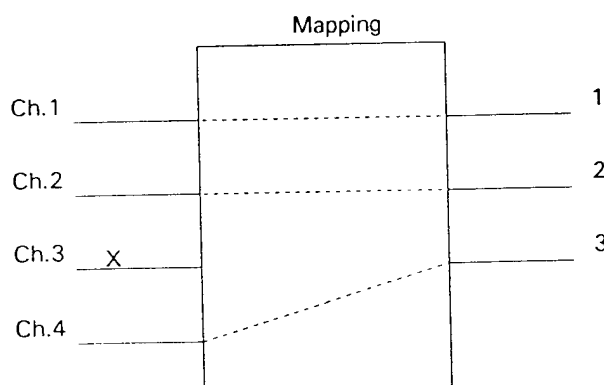


Fig. 9.b Mapping after Ch.3 is lost



(b) What happens to the lost packets?

Two approaches can be taken:

(1) One is that we can influence the design of the video encoder regarding the implementation of different methods of image recovery, such as interpolation, predictive coding, etc.

(2) The other approach is for the case where we have no influence over the video encoder design. In this case we mark the lost frame (fill the frame with a black image) and let the video encoder work with it.

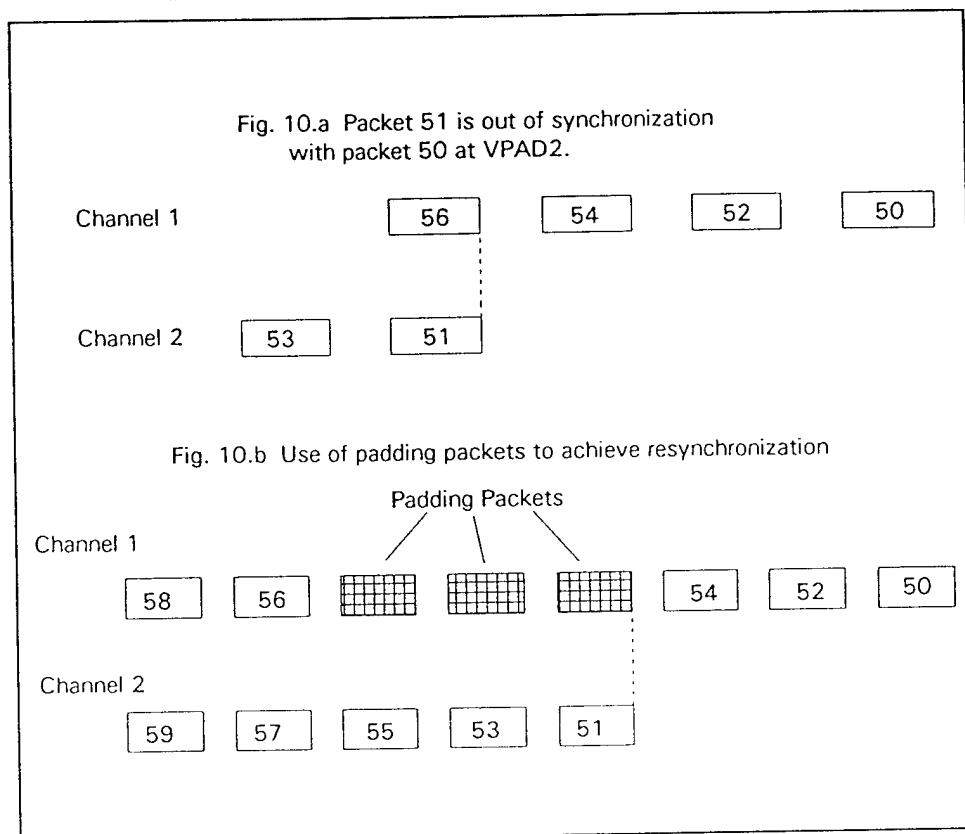
Ideally, we should have forward error correcting (FEC) capabilities. However, FEC codes are expensive and normally they require a large number of redundant bits (could be equal to the video bits). In this case, the use of CRC is more economical and it can be used as an alarm to the

7.6 RE- SYNCHRONIZA- TION

video encoder. It is not meant to be used as an automatic request error control procedure due to the real time nature of the video signal.

At some point during the video transmission, resynchronization might be needed. For example, consider that at VPAD2, Channel 1 is off by two packets with respect to Channel 2 (See Figure. 10.a). Channel 1 has received Video Packets (VP) 50 and 52, and while receiving VP 54, Channel 2 is receiving VP 51. In this case Channel 1 is ahead by two packets. VPAD2 then sends a Resynchronization Message to VPAD1 to prevent buffer overflow.

In Figure.10.b we illustrate the case where the estimated delay at VPAD1 for Channel 1 is too large with respect to Channel 2. This time difference is reduced by sending two Padding Packets (dummy unnumbered video packets) so that both channels can be synchronized.



8.0 INDUSTRY PRODUCT STATUS

8.1 METHODOLOGY

A search was made of companies advertising activity in video compression or transmission techniques involving video data. Twelve companies were found which had not previously been approached during the initial survey. These companies are listed below:

Colorado Video, Inc	Boulder, CO
Comtech Comm Corp.	Hauppauge, NY
Concept Communications	Dallas, TX
Delta Information Systems	Horshom, PA
Grass Valley Group	Silver Springs, VA
Hughes Aircraft	Los Angeles, CA
Harris Corp.	Melborne, FL
Leitch Video of America	Chesapeake, VA
Parallax Graphics	Santa Clara, CA
Pierce-Phelps Inc.	Philadelphia, PA
Picture Conversion Inc.	Falls Church, VA
Scientific-Atlanta Inc.	Atlanta, GA

A letter explaining the government's interest in video compression techniques and requesting information and interest in this field was transmitted to each of the above listed companies.

8.2 SURVEY ANALYSIS

The responses were not encouraging. While five companies responded to the inquiry, one stated "no interest," four of the companies were in the "freeze frame" business and had no products which could be adapted to the Army's requirements. Concept Communications, which was considered the most promising candidate during the initial survey, had been sold and relocated to Dallas, TX. As a result of these changes, their business focus was not clear. Currently, the only producer of a video compressed product is PicTel, Inc. This system was described in the initial study for CECOM.

8.3 CONCLUSION

Clearly video and video compression technologies are making rapid improvements. Further the changing nature of the battlefield and the expectation of today's and tomorrow's soldier for video services requires that the army contemplate provision of video transmission on MSE networks. These investigators feel that there is adequate evidence that coding and decoding techniques will be developed by private industry. Further the investigators believe that it is prudent that the army begin investigating prototype video packet assembler/disassembler components permitting MSE to cope with emerging video requirements.

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Appendix A

The MSE equipment is intended to provide service to the Corps and Division Area subscribers. Depending on the battle scenario, between 42 to 56 switches (Nodes) have been proposed to provide service to the subscribers within this zone. Some services would extend forward to the Division area. These nodes and their capabilities are described below:

A.1 NETWORK

The MSE network will be deployed in a grid having north, south, east and west connectivity from the major trunking nodes which are interconnected via line of sight (LOS) radio or satellite terminals in the UHF range. As many as 12 or more large trunking nodes will provide the trunking grid network.

A.2 NODE CENTER SWITCH

The Node Center Switch (NCS) is the largest switch of the MSE system with a capacity of over 600 terminations. Its 16 digital trunk groups allow interconnection to other NCS', large extension nodes (LEN), small extension nodes (SEN), Radio Access Units (RAU), and radio assemblages. Local subscribers are limited to 24 terminations, which mainly provide telephone service to the switch operating personnel.

A.3 LARGE EXTENSION NODE (LEN)

The Large Extension Node (LEN) has as a primary function, providing telephone services to local subscribers and terminating incoming calls from the trunk network. The LEN can accommodate 176 subscribers directly connected through junction boxes wired to telephone instruments and other subscribers entering in loop groups. Radio access units (RAU) are also accommodated by the LEN.

A.4 SMALL EX- TENSION NODE (SEN)

The Small Extension Node (SEN) is fielded in two versions with 26 or 41 local subscriber capacity. As an extension node, its function is to provide local telephone service as well as inter-connection to the area communications network.

A.5 SUBSCRIBER ACCESS MODES

Subscribers connect to the MSE/TRITAC switches either as one channel in a multiplexed loop group or as individual wired connections. In both options, the subscriber is responsible for the wired connection to either the loop group access panel or the switch junction box. Both the LEN and SEN switch configurations carry sufficient junction boxes with multipair 50 foot cables. Each cable and junction box allows for connection of 13 4-wire subscribers. Group connections are 13 duplex multiplexed channels for remote subscribers connected via coax cable or RF transmission systems. Group connections require the synchronization of the channels. The multiplexers therefore, steal the least significant bits from the first channel to effect the framing of the group. Voice users are slightly degraded by this loss but data users might be totally disrupted by the bit loss.

Terminal encryption devices also require security synchronization which again would further impact the transfer of data unless the bit orientation is embedded into the data transfer algorithm. The system design of the different data devices must consider the implications of both encryption and group connections.

One other factor which affects the subscriber is the need for the "Affiliation" function for each terminal. The MSE voice subscriber upon connection to a switch, must enter his Personal Identification Number. These unique codes are distributed through-out the Army forces. These PIN codes are verified by the network control element and the allocated services are then authorized to the subscriber. Based upon the predetermined combinations of services, i.e. precedence, conferencing, global access, commercial access, etc., the subscriber is then able to use the switch features. At the present time, there are no class-marked combination of features which would encompass any multiple line data user. To allocate a new "multi-line data unique subscriber," changes to the software of the switches and the control element may be necessary.